From Toy Models to Tactical Concerns: Assessing the Dual-Use Potential of Emergent Gravity in Quantum Simulators

Douglas C. Youvan

doug@youvan.com

June 4, 2025

A groundbreaking theoretical study, *Emergent Holographic Forces from Tensor Networks and Criticality* (Sahay, Lukin, Cotler, 2024), demonstrates how gravity-like interactions can arise from entanglement patterns in quantum spin chains. This advance offers experimental insight into the long-speculated AdS/CFT correspondence and the broader question of how spacetime may emerge from quantum information. While framed as a "toy model," the implications of simulating gravitational attraction through entanglement are profound—not only for physics, but for national security and global ethics. History shows that theoretical breakthroughs, from nuclear physics to cryptography, often evolve into tools of strategic importance. This paper explores the dual-use trajectory of quantum gravity research, outlining how programmable quantum simulators might eventually support exotic field manipulation, entanglement-based control systems, or unforeseen weaponization pathways. With early implementation possible on existing quantum platforms like Rydberg atom arrays, the threshold between abstract theory and deployable capability may be closer than anticipated. Our goal is to identify the contours of emerging risk while proposing policy safeguards that balance scientific openness with responsible innovation.

Keywords: quantum gravity, AdS/CFT, tensor networks, MERA, dual-use, emergent spacetime, quantum simulation, entanglement, holography, field manipulation, Rydberg atoms, quantum ethics, military applications, theoretical physics, critical systems, national security, toy model, programmable quantum systems, quantum sensing, information weaponry. A collaboration with GPT-4o. CC4.0.

1. Abstract

This white paper explores the dual-use implications of a groundbreaking quantum gravity simulation model presented in the scientific study *"Emergent Holographic Forces from Tensor Networks and Criticality"* by Rahul Sahay, Mikhail D. Lukin, and Jordan Cotler (arXiv:2401.13595v1). The study proposes a concrete and testable model for simulating aspects of the AdS/CFT correspondence using a multi-scale entanglement renormalization ansatz (MERA), revealing how gravitational-like attractive interactions can emerge from quantum entanglement structures in a critical spin chain system.

Purpose of the Paper
The primary goal of this paper is to assess the potential for dual-use—civilian and military—arising from foundational research in quantum gravity simulation. While the original work is situated firmly within theoretical and computational physics, and presented as a toy model for exploring aspects of the AdS/CFT correspondence, this paper considers long-term technological trajectories that could transform such conceptual frameworks into tools with strategic utility. Drawing from historical precedents in nuclear physics, cryptography, and quantum information science, we identify markers that signal when pure research may cross into dual-use territory.

Overview of the Scientific Study
The referenced study develops a quantum circuit model that simulates the dynamics of a two-dimensional bulk gravitational theory using a one-dimensional critical quantum spin chain. This mapping leverages a tensor network architecture (MERA) to represent entanglement across multiple scales. By inserting excitations into the network and analyzing the resulting bulk dynamics, the authors observe that these excitations interact through attractive potentials that closely match those predicted by classical general relativity in anti-de Sitter (AdS) space.

Critically, this gravitational-like interaction is not explicitly programmed into the system; it arises naturally from the structure of the entanglement and the renormalization flow intrinsic to the MERA network. The authors note that this model is suitable for implementation on present-day quantum simulation

platforms, such as neutral atom arrays, making it one of the most experimentally viable demonstrations of emergent geometry from quantum entanglement to date.

Statement on Dual-Use Concern
While the authors describe their construction as a “toy model,” the broader context of technological development suggests that such models may serve as early templates for applications far beyond their original academic intent. The ability to engineer emergent forces, geometries, or field-like behaviors from entangled quantum substrates raises fundamental questions about future capabilities. These include potential uses in quantum sensing, quantum control of spacetime-like metrics, field manipulation, or exotic energy concentration systems.

This paper asserts that even abstract and simplified models, when grounded in precise computational and physical architectures, can act as incubators for dual-use technologies. As such, their development and dissemination warrant proactive consideration by both the scientific and defense communities.

2. Background

This section provides the foundational concepts necessary to understand the scientific framework and implications of the study under consideration. It introduces the AdS/CFT correspondence as a theoretical lens, explains the tensor network architecture used in the simulation, and summarizes the specific contribution of the 2024 study by Sahay, Lukin, and Cotler.

2.1. The AdS/CFT Correspondence

Definition and Significance
The Anti-de Sitter/Conformal Field Theory (AdS/CFT) correspondence is a conjectured duality proposed by Juan Maldacena in 1997. It posits a one-to-one mapping between a gravitational theory in a bulk AdS (Anti-de Sitter) spacetime

and a conformal field theory (CFT) defined on the boundary of that spacetime. In its canonical form, it relates a (d+1)-dimensional theory of gravity to a d-dimensional non-gravitational quantum field theory.

This duality has immense theoretical significance because it suggests that gravity, space, and time could be emergent phenomena arising from a more fundamental, non-gravitational quantum theory. In effect, it provides a non-perturbative definition of certain quantum gravity theories using well-understood quantum field theories.

Relevance to Theoretical Physics and Quantum Gravity Research
AdS/CFT offers a concrete framework for studying quantum gravity—an area that has long resisted unification with quantum mechanics. The correspondence has shed light on:

- Black hole entropy and information paradoxes
- Quantum entanglement as a mechanism for spacetime connectivity
- Holographic principles (the idea that a lower-dimensional system can encode higher-dimensional physics)

Because AdS/CFT bridges gravitational and non-gravitational realms, it also has implications for high-energy physics, condensed matter theory, and quantum information science. The correspondence is now a central theoretical tool for probing the deep structure of spacetime and may serve as a roadmap for developing practical quantum gravity models.

2.2. Tensor Networks and the MERA Architecture

Explanation of MERA and Entanglement Renormalization
Tensor networks are graphical representations of quantum many-body states, where nodes represent multi-index tensors and edges represent quantum entanglement between subsystems. Among the most powerful of these is the Multi-scale Entanglement Renormalization Ansatz (MERA), which is specially designed to capture the scaling and long-range correlations of critical systems.

MERA implements a real-space renormalization group (RG) flow via two types of operations:

- Disentanglers, which remove short-range entanglement
- Coarse-grainers (isometries), which reduce the number of degrees of freedom at each scale

Together, these operations generate a hierarchical structure that maps the ultraviolet (high-resolution) degrees of freedom to infrared (coarse-grained) descriptions. The result is a tensor network that mimics the behavior of conformal field theories and has a natural geometric interpretation resembling a discretized hyperbolic space—strikingly similar to the AdS geometry.

Use of MERA in Modeling Critical Systems and Simulating Bulk Behavior
MERA is particularly well-suited for simulating quantum critical systems—those at the transition point between two distinct quantum phases. These systems exhibit long-range entanglement patterns that cannot be efficiently captured by simpler tensor networks.

Because of MERA's scale-invariance and hierarchical structure, it has been proposed as a discrete model of the AdS/CFT correspondence. The spatial layering in the tensor network maps naturally to the radial coordinate in AdS space, and excitations in the tensor network can be interpreted as bulk field dynamics. This geometrization of entanglement lays the groundwork for simulating how spacetime or gravitational behavior may emerge from purely quantum informational foundations.

2.3. The Specific Study: Summary of arXiv:2401.13595

Construction of a Toy AdS/CFT Model
In the 2024 paper *"Emergent Holographic Forces from Tensor Networks and Criticality"*, the authors present a concrete realization of an AdS/CFT-inspired model using a MERA tensor network. They begin with a (1+1)-dimensional critical spin chain governed by a specifically chosen Hamiltonian tuned to a conformal

point. By constructing a scale-invariant MERA representation of this system, they define a mapping from boundary qubits to a (2+1)-dimensional “bulk” theory.

This bulk theory arises from viewing the MERA circuit in reverse, with excitations in the tensor network interpreted as bulk particles. Importantly, the authors construct a dual Hamiltonian in the bulk by conjugating the boundary Hamiltonian through the MERA circuit.

Simulation of Attractive Bulk Excitations Resembling Gravitational Forces
The core result of the paper is that excitations in the emergent bulk interact through attractive potentials, matching the expected energy behavior of particles in AdS space. Single-particle excitation energies grow exponentially with radial distance from the center of the network—mirroring the gravitational potential in (2+1)-dimensional AdS spacetime. Two-particle interactions also show distance-dependent attraction, reinforcing the interpretation of emergent gravitational forces.

These results are supported both numerically and analytically through the renormalization properties of the MERA structure. The appearance of gravitational-like potentials is not put in by hand but arises from the entanglement renormalization process itself.

Feasibility on Current Quantum Simulation Platforms
Significantly, the authors emphasize that their model is experimentally realizable using existing quantum simulation technologies. They propose implementing the critical spin chain and corresponding holographic circuit using Rydberg atom tweezer arrays or trapped ion platforms—both of which are capable of realizing the required Hamiltonians and entanglement structures.

This makes the study not just of theoretical interest but also of practical relevance: it opens the door to real-world experiments simulating aspects of quantum gravity. As a result, the study stands as one of the first feasible implementations of holographic duality using tools from quantum computing and quantum information science. While still a toy model, it validates the idea that spacetime-like behavior can emerge from entangled quantum systems—a principle that may

eventually inform the design of advanced technologies with both scientific and strategic implications.

3. Assessing Dual-Use Potential

This section evaluates the dual-use implications of the MERA-based AdS/CFT toy model, as presented in the referenced study. Although the research is theoretical and academic in nature, the underlying methods and the direction of technological development suggest potential future applications beyond civilian science. Drawing on historical analogs and analyzing the nature of the entanglement-based simulation, we explore how this line of work could intersect with defense interests.

3.1. Definition of Dual-Use in Theoretical Physics

Historical Precedents

The concept of “dual-use” refers to scientific research and technology that can serve both peaceful and military purposes. Several notable examples from modern history illustrate how foundational theoretical research has later been repurposed—or directly applied—for military development:

- Nuclear Physics: Research into atomic structure and energy led to the development of nuclear weapons. Theoretical insights by Fermi, Oppenheimer, and others were initially pursued for scientific understanding but were co-opted by the Manhattan Project.
- Cryptography: Theoretical work in number theory and abstract algebra now underpins modern cryptographic systems. These systems are critical for both civilian privacy and military command-and-control security.
- Lasers: Initially a product of quantum electrodynamics and optical theory, lasers now play roles in directed-energy weapons, missile guidance, and sensing systems.

These cases show that even abstract, mathematical, or simulation-based research—when paired with sufficient technological capability—can lead to weaponization trajectories.

Criteria for Dual-Use Concern
To assess dual-use potential in a new domain such as quantum gravity simulation, several criteria should be considered:

- Scalability: Can the core principle be extended to larger or more powerful systems?
- Controllability: Does the model suggest pathways for precise manipulation of fields, energies, or information?
- Convertibility: Can the theoretical model be realized or encoded in physical systems with current or near-term technology?
- Unpredictable Emergence: Does the research create new domains where control or prediction of emergent behavior could lead to strategic advantage or threat?

In the context of the referenced study, all of these criteria are either met or plausibly addressable within future developments in quantum hardware and information theory.

3.2. Theoretical Pathways to Weaponization

Control Over Emergent Spacetime-Like Geometries
The MERA-based simulation demonstrates that spacetime-like curvature and attractive gravitational potentials can be encoded into and emerge from entanglement structures. If such control were extended, it could lead to the theoretical design of synthetic geometries that mimic field effects, including curvature, confinement, or energy gradients. In the extreme case, one could envision engineered “zones” of manipulated information density or propagation delay—an idea reminiscent of exotic spacetime engineering.

Entanglement Engineering as a Tool for Field Manipulation
Entanglement is not simply a correlation; it is a resource that can structure information, influence energy distributions, and determine how systems evolve. In the context of AdS/CFT simulations, entanglement patterns effectively determine the geometry of the emergent bulk. If these patterns can be dynamically engineered, they could become a tool for localized control of effective potentials—potentially giving rise to entanglement-mediated field manipulation. This would have implications for sensing, shielding, and energy focus in both physical and information-theoretic domains.

Simulation-Driven Optimization of Energy Configurations and Matter Behavior
One of the practical outputs of a quantum gravity simulator is the ability to model how energy and matter behave under conditions not easily accessible in classical physics or in real-world experiments. Such simulations could inform the design of:

- Field configurations that trap or deflect matter or energy
- Materials with exotic phase transitions under extreme conditions
- Energy transfer protocols in high-density, non-linear regimes

These capabilities could become central to the design of next-generation propulsion, shielding, or high-impact field systems—especially if coupled with artificial intelligence for optimization.

3.3. Experimental Infrastructure and Potential Exploitation

Quantum Simulation Platforms with Defense Funding
Quantum simulation platforms capable of running the referenced MERA-based model are already being developed with support from defense agencies such as DARPA, IARPA, and equivalents abroad. Technologies such as Rydberg atom arrays, superconducting qubits, and trapped ion systems are being used not only for fundamental science but also for secure communications, intelligence processing, and advanced materials development. Embedding AdS/CFT-like models within

these platforms may lead to unanticipated forms of control over collective quantum behavior.

Long-Term Scenarios for Entanglement-Based Field Control or Sensing
In the long term, controlled entanglement architectures may enable:

- High-resolution, long-range quantum sensing or imaging
- Dynamic field modulation via entangled “qubit webs”
- Quantum synchronization and coordination across distributed defense assets

Such systems might operate in environments where classical signals are blocked, degraded, or intercepted—making them highly valuable for secure communication, surveillance, or battlefield control.

Use in Modeling Extreme Conditions (e.g., Nuclear Detonation, EMP Environments)
AdS/CFT-inspired simulations offer the ability to model strong-coupling regimes—precisely the domains where nuclear interactions, plasma behavior, and extreme field configurations become analytically intractable. Quantum simulation models could be used to:

- Optimize energy delivery in pulse-form weapons
- Model EMP propagation and shielding under realistic conditions
- Predict the behavior of exotic matter or vacuum states under artificial constraints

These use cases remain speculative but fall within the foreseeable scope of technological maturation, especially as quantum simulators scale up in size, speed, and configurability.

Conclusion of Section
While the study by Sahay, Lukin, and Cotler is fundamentally a theoretical and academic endeavor, it opens the door to a class of quantum simulations where

emergent geometry and entanglement-induced forces are not merely metaphors but programmable, testable behaviors. These models, if developed further and coupled with advances in quantum hardware, may offer strategic capabilities that merit early ethical, scientific, and policy-level oversight.

4. Risk Assessment Timeline

This section outlines the projected stages of dual-use risk based on anticipated advancements in quantum simulation, quantum hardware, and theoretical physics. While the current work remains academic and exploratory, historical precedent in theoretical physics (e.g., quantum mechanics, nuclear theory, and condensed matter) shows that fundamental research can evolve—often unpredictably—into applied domains, including defense and weapons development. By examining the trajectory from proof-of-concept to scalable implementation, we categorize dual-use risk over three successive time horizons.

4.1. Near-Term (1–5 Years)

Minimal Risk: Limited to Academic and Proof-of-Concept Simulations

In the immediate future, the dual-use potential of the referenced MERA-based AdS/CFT simulation model remains low. Research is constrained to:

- Small system sizes: Typical quantum simulators operate with tens to a few hundred qubits, limiting the complexity and scalability of the simulation.
- Fixed architectures: Most quantum hardware platforms are not yet flexible or modular enough to explore wide-ranging variations of spacetime emergence or dynamic field engineering.
- Conceptual focus: The goal of the research is to test theoretical ideas, not to engineer systems for practical utility or control.

Nonetheless, this period is crucial for laying the groundwork. During this time, the theoretical language, toolkits, and computational frameworks developed will

shape future directions. The risks may not lie in immediate application, but rather in the quiet accumulation of methods and architectures that can later be redirected toward strategic ends.

4.2. Mid-Term (5–15 Years)

Increased Capabilities in Programmable Quantum Simulators
Modeling Nontrivial Field Interactions or Materials with Exotic Properties

The mid-term horizon represents the onset of significant risk, as both hardware and theoretical sophistication improve:

- Programmable quantum simulation platforms will reach new levels of fidelity and scale. Devices based on Rydberg atoms, trapped ions, and superconducting qubits will be capable of running increasingly complex entanglement networks and Hamiltonians.
- Dynamic entanglement control could allow for real-time modulation of effective potentials in synthetic geometries.
- Multi-scale simulations of materials or fields with strong coupling (e.g., quantum chromodynamics analogs, condensed matter under stress, emergent metric fields) could provide design feedback for advanced materials, energy channeling mechanisms, or phase-control in field-based technologies.

This is the phase where theoretical and experimental convergence begins to blur the line between simulation and application. Simulators may start mimicking behaviors that, while not gravitational in the Einsteinian sense, carry field-theoretic consequences, such as localized curvature, information flow constraints, or energy confinement—tools of potential interest to those developing advanced stealth, propulsion, or directed-energy systems.

4.3. Long-Term (15+ Years)

Possible Convergence with Topological Quantum Computing, Quantum AI, or High-Field Control Systems
Potential for Entanglement-Based “Information Weapons” or Field Modulation Systems

In the long-term scenario, the convergence of multiple technological streams could bring transformative, and potentially dangerous, capabilities online. These include:

- Topological quantum computing: Capable of robust, fault-tolerant operations over extended networks, potentially useful for constructing large-scale entanglement architectures immune to decoherence.
- Quantum-enhanced artificial intelligence: May drive the discovery or optimization of exotic Hamiltonians that produce emergent properties unknown to classical physics, including metric manipulation or non-local field behavior.
- Entanglement-based field modulation: Systems could emerge where entangled qubit lattices are used to encode, direct, or reshape information and energy in space—functioning as “information warping” engines or targeting systems based not on kinetics, but on coherence, phase, or topology.

The most speculative but consequential outcome is the development of entanglement weapons: tools that exploit controlled non-locality to interfere with communications, computation, or physical systems at a distance, potentially bypassing classical barriers. Alternatively, field-based modulation platforms could be used to sculpt or disrupt physical environments via engineered resonance or entropic gradients.

Even absent hostile intent, such capabilities might create new classes of infrastructure vulnerabilities, raise questions of attribution, and provoke strategic instability.

Summary of Risk Timeline

Time Horizon	Key Risks	Risk Level
1–5 years	Proof-of-concept simulations; knowledge consolidation	Low
5–15 years	Programmable quantum field simulations; exotic material modeling	Moderate to High
15+ years	Scalable, AI-guided entanglement engineering; potential field or information weapons	High

The timeline highlights that while the direct threat is not immediate, the groundwork for transformative dual-use technologies is actively being built today. Proactive engagement across scientific, ethical, and strategic communities is essential to anticipate, guide, and possibly limit unintended consequences.

5. Ethical and Strategic Considerations

As quantum technologies progress toward increasing power and generality, the boundary between fundamental research and militarily actionable capability becomes increasingly porous. This section examines the ethical obligations and strategic responsibilities of researchers, institutions, and governments in managing dual-use trajectories. Specifically, we address the tension between scientific openness and national security, and the need for cooperative frameworks that prevent destabilizing developments in quantum simulation and quantum gravity research.

5.1. Transparency in Dual-Use Research

Recommendations for Publishing and Oversight

The conventional ethos of scientific inquiry relies heavily on openness, reproducibility, and the free exchange of knowledge. However, when research crosses into territory with clear dual-use implications—such as the simulation of emergent gravitational phenomena or entanglement-based field control—this openness must be weighed against potential downstream applications.

To strike this balance, we recommend the following:

- Independent Review Boards: Research institutions, particularly those receiving public or defense funding, should convene independent interdisciplinary review boards to assess the dual-use potential of publications involving advanced quantum simulation, entanglement networks, and emergent geometry models.
- Pre-publication Risk Disclosure: Authors of high-risk research should be encouraged (or required) to include a dual-use risk statement, akin to conflict-of-interest declarations in biomedical science.
- Journal Guidelines: Peer-reviewed journals in physics and quantum information should adopt editorial policies that recognize and address the potential for dual-use applications—particularly in fields overlapping with field theory, condensed matter emulation, and quantum computing.

Open Access vs. Restricted Application Pathways

The shift toward open access publishing has democratized scientific knowledge, but it also enables global dissemination of findings that may have sensitive implications. In the case of work like Sahay, Lukin, and Cotler's MERA-based AdS/CFT simulation, the explicit experimental realizability of the model raises questions about who may act on this knowledge and how.

To navigate this, a tiered model of disclosure could be considered:

- Open Access for Theoretical Foundations: General theoretical insights should remain openly accessible to ensure the continued flourishing of

science and to prevent secrecy from becoming a pretext for monopolizing knowledge.

- Restricted Disclosure for High-Precision Experimental Techniques: Specific quantum circuit configurations or optimization methods that demonstrate gravitational or field-like emergent behavior could, in certain contexts, be flagged for limited-access repositories, particularly when they approach scalability or demonstrate utility for field manipulation.

Ultimately, scientific freedom must be preserved, but not without mechanisms to understand and mitigate risks. Transparency should extend not only to publication, but to intent and collaborative purpose.

5.2. Strategic Deterrence and Preemptive Norms

Importance of International Collaboration and Treaties on Emerging Tech
The development of nuclear weapons during the mid-20th century ushered in a new era of international security policy centered on arms control, deterrence, and treaties such as the Non-Proliferation Treaty (NPT). While quantum gravity simulations and tensor network research are not yet at such a critical threshold, the time to establish preemptive norms is now—before advanced quantum systems become points of geopolitical competition.

We recommend:

- Initiating Diplomatic Frameworks for discussing dual-use quantum technologies under existing science and technology arms control forums, such as the UN Office for Disarmament Affairs (UNODA) or the Convention on Certain Conventional Weapons (CCW).
- Building Cross-Border Research Trust through cooperative experiments, transparent modeling efforts, and shared use of quantum simulators where feasible.
- Establishing a Scientific Track-II Dialogue—informal but structured conversations between scientific advisors and policy makers across major

quantum R&D nations (e.g., U.S., China, EU, Russia, India)—to prevent the inadvertent arms-race development of technologies based on theoretical-to-practical conversion.

Avoiding Adversarial Development of Theoretical-to-Practical Conversion Pipelines
The most dangerous pathway is not the direct militarization of science but the systematic transformation of abstract theoretical models into weaponizable frameworks through targeted investment, classified experimentation, and adversarial engineering.

To prevent this:

- Monitoring of Quantum Infrastructure should go beyond cyber- and hardware-level security to include scrutiny of the architectures being implemented in state-funded labs, particularly those simulating strongly coupled systems or emergent field dynamics.
- Red Teaming Within Academia should be encouraged, where theoretical physicists and engineers are tasked with identifying unintended uses of emerging research and feeding this back into institutional oversight mechanisms.
- Ethics and Security Education should be integrated into physics and computer science graduate training, especially in quantum information science programs. Awareness, not just brilliance, must become a credential for leadership in this field.

Conclusion of Section
As the study of quantum information and emergent gravity progresses from toy models to laboratory systems, the strategic and ethical challenges multiply. The risks are not in the math itself, but in its contextual transformation—when scale, funding, and intent converge. The quantum era will not pause for regulation; it is therefore the obligation of scientists, governments, and international institutions to foresee, and shape, the contours of responsibility.

6. Policy Recommendations

To responsibly manage the dual-use potential of emerging quantum technologies—particularly those involving quantum simulation, entanglement-based geometry, and toy models of quantum gravity—governments and research institutions must take proactive steps. This section outlines targeted, implementable policy recommendations designed to preserve the vitality of basic research while reducing the likelihood of unintended militarization or destabilizing technological convergence. The recommendations focus on funding structure, institutional oversight, and interdisciplinary dialogue.

Funding Safeguards for Basic Science Research in Quantum Gravity

While state and private investment in quantum research continues to grow, especially through initiatives focused on national security and technological competitiveness, it is essential to ensure that basic research in quantum gravity remains protected from premature classification, strategic redirection, or commercial lock-in. The intellectual ecosystem that produced breakthroughs such as the AdS/CFT correspondence and tensor network modeling must remain open and collaborative.

To this end, we recommend:

- Maintaining a public funding baseline for non-applied quantum gravity research under agencies such as the NSF, European Research Council, and equivalent national science bodies. These funds should support work that is exploratory and unconstrained by application timelines.
- Mandating disclosure of intent in grant applications for projects that involve entanglement simulation, AdS modeling, or tensor network architectures—clarifying whether the work is foundational or aimed at applied development.

- Prohibiting early-stage quantum gravity grants from becoming proprietary or subject to restrictive IP frameworks until the theoretical viability of applied use is better understood.

Funding safeguards must ensure that intellectual freedom is not inadvertently redirected into high-risk domains without appropriate oversight or ethical scrutiny. Protecting foundational research also serves as a strategic hedge: it ensures that civilian and academic institutions retain influence over the narrative and trajectory of quantum gravity technologies.

Advisory Boards for Dual-Use Risk in Emerging Quantum Simulations

As the scope and complexity of quantum simulation platforms grow, so too does the potential for unintended weaponization of theoretical models. The referenced study, which shows how gravity-like forces emerge from a quantum spin chain via tensor networks, exemplifies how theoretical insights can quickly approach experimental realizability.

To provide foresight and structured analysis, we recommend the formation of permanent or rotating advisory boards composed of:

- Theoretical physicists specializing in quantum gravity, quantum field theory, and tensor networks
- Quantum hardware experts (e.g., from quantum computing and simulation platforms)
- Strategic analysts with experience in defense technologies and arms control
- Ethicists and science policy professionals

These boards should be embedded in:

- National science funding agencies (e.g., DOE, DARPA, DFG, CSIRO)
- University-level quantum research centers
- International scientific consortia focused on quantum tech governance

Their primary responsibilities would include:

- Reviewing high-impact simulation proposals for dual-use risks
- Developing internal risk scoring and classification mechanisms for research in critical areas
- Advising on thresholds beyond which international notification or cross-institutional consultation becomes appropriate

Such boards would not inhibit research but enable risk-aware innovation, providing a defense-informed, scientifically literate buffer between basic research and potential misuse.

Encouragement of Interdisciplinary Review Between Defense Analysts and Theoretical Physicists

One of the critical vulnerabilities in emerging tech oversight is the disciplinary divide between those who develop the science and those tasked with assessing its strategic implications. In the domain of quantum gravity and holographic simulations, the theoretical sophistication is often beyond the reach of conventional defense analysis, while physicists may remain unaware of how their models could be translated into technical architectures of concern.

To bridge this gap, we recommend:

- Establishing interdisciplinary working groups modeled after successful models in bioethics and nuclear deterrence, where participants include physicists, engineers, policy makers, and military science advisors.
- Hosting joint scenario workshops where toy models (such as the MERA-AdS/CFT simulation) are reviewed not just for scientific merit but for conceivable trajectories toward physical instantiation, and potential dual-use paths are mapped.
- Incorporating dual-use case studies into physics curricula—including examples like quantum cryptography, quantum radar, and emergent

geometry—to foster early awareness and cultural competence within the next generation of researchers.

Defense analysts must be given the intellectual tools to ask meaningful questions about cutting-edge simulations, while physicists must be encouraged to consider how their models might be repurposed under different funding or institutional pressures.

Conclusion of Section

Policy intervention in emerging science is often reactive—arriving only after irreversible technologies have matured. In the case of quantum gravity simulation and entanglement-based field modeling, we still have time. By embedding safeguards at the funding level, constructing advisory oversight mechanisms, and facilitating meaningful interdisciplinary review, we can avoid both the stagnation of innovation and the blind acceleration of theoretical research into strategic weapon systems.

Science, especially at the frontiers of reality, must remain free—but not naive. These recommendations seek to ensure it remains both.

7. Conclusion

The rapid advancement of quantum technologies—particularly in the realm of quantum simulation, entanglement networks, and holographically inspired models—demands a renewed vigilance in how we assess and govern foundational research. While the study at the center of this paper, *"Emergent Holographic Forces from Tensor Networks and Criticality"* (arXiv:2401.13595v1), is described by its authors as a toy model, it nonetheless exemplifies a broader shift in physics: the transition from abstract theory to programmable, entanglement-driven architectures capable of modeling gravitational-like forces and spacetime-like geometries within laboratory systems.

Summary of Findings

This white paper has provided an in-depth analysis of how a toy model of the AdS/CFT correspondence, built using the MERA tensor network, may be the first step in a longer arc toward dual-use applications. The study demonstrates that entanglement structures alone can generate emergent behavior that mirrors classical gravitational attraction in AdS space. Though still far from the complexity and scale of actual spacetime, such results suggest that gravitational dynamics are not inherently classical or geometric—they can be algorithmic, programmable, and emergent.

We have explored how this capacity, in its current and anticipated forms, intersects with national security interests, and what this may imply for the development of advanced sensing, field manipulation, or information-theoretic weapons. In this context, we have drawn lessons from historical dual-use precedents, offered a risk timeline, and proposed concrete ethical and policy mechanisms to address these emerging realities.

Final Statement: Even Toy Models Can Trace the Outlines of Future Capability

Toy models, by design, simplify the world in order to understand it. But when those simplified systems reproduce core behaviors of fundamental forces, they become more than theoretical exercises—they become blueprints. Just as early simulations of atomic behavior eventually informed nuclear design, these quantum simulations may someday inform technologies that manipulate space, time, or information with unprecedented precision. What today is a metaphorical gravity well in a tensor network could, tomorrow, be part of an engineered energy landscape.

The challenge before us is not merely technical. It is epistemic and ethical: how do we distinguish between harmless exploration and foundation-laying for strategic capability? How do we preserve the openness of science without abdicating responsibility for where it leads?

The Importance of Watching the Horizon Before the Tools Arrive

By the time technologies mature into actionable systems, the governance window often closes. Once hardware is in place, economic and military incentives

dominate the discourse. The horizon, therefore, must be watched from a distance—while the work is still abstract, the designs still mathematical, and the consequences still avoidable.

This paper calls for strategic foresight grounded in scientific literacy. It urges institutions and nations to engage not only with the tools of the present, but with the patterns they forecast. In the age of quantum emergence, the gravity we simulate may become the force we wield. Whether that force is stabilizing or destabilizing depends, not on the equations, but on the choices we make while the models are still small.

8. References

This section provides the foundational sources and supporting literature used throughout this white paper. It includes the primary study under analysis, key background material on both the technical and strategic dimensions of dual-use science, and institutional frameworks for ethical and policy oversight of emerging technologies with security implications.

Primary Study Analyzed

Sahay, R., Lukin, M. D., & Cotler, J. (2024). *Emergent Holographic Forces from Tensor Networks and Criticality*. arXiv:2401.13595v1 [quant-ph]. https://arxiv.org/abs/2401.13595

This paper proposes a MERA-based tensor network model for simulating AdS/CFT duality, demonstrating how bulk excitations governed by long-range entanglement exhibit gravity-like attraction. It is presented as a toy model but is experimentally implementable with current quantum simulation platforms.

Supporting Literature: Dual-Use History and Theoretical Physics

- Kevles, D. J. (1990). *The Physicists: The History of a Scientific Community in Modern America*. Harvard University Press.
    - Explores the intersection of theoretical physics and government during the 20th century, including the Manhattan Project.
- MacKenzie, D. (1991). *Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance*. MIT Press.
    - Chronicles how abstract mathematical and technical systems evolved into precise military technologies.
- Guillemin, J. (2005). *Biological Weapons: From the Invention of State-Sponsored Programs to Contemporary Bioterrorism*. Columbia University Press.

- Provides historical precedent for how scientific programs with civilian aims became part of national security strategies.

- Joy, B. (2000). *Why the Future Doesn't Need Us*. *Wired*, Issue 8.04.
  - Early warning on the dangers of self-replicating and dual-use technologies, including AI and nanotechnology.

Supporting Literature: MERA, AdS/CFT, and Entanglement

- Vidal, G. (2007). *Entanglement Renormalization*. Physical Review Letters, 99(22), 220405.
  - Introduces the MERA tensor network as a framework for simulating quantum many-body systems at criticality.
- Swingle, B. (2012). *Entanglement Renormalization and Holography*. Physical Review D, 86(6), 065007.
  - Proposes the connection between MERA and the AdS/CFT correspondence.
- Maldacena, J. (1999). *The Large-N Limit of Superconformal Field Theories and Supergravity*. International Journal of Theoretical Physics, 38, 1113–1133.
  - The original proposal of the AdS/CFT correspondence.
- Pastawski, F., Yoshida, B., Harlow, D., & Preskill, J. (2015). *Holographic Quantum Error-Correcting Codes: Toy Models for the Bulk/Boundary Correspondence*. Journal of High Energy Physics, 2015(6), 149.
  - Introduces quantum error-correcting codes as a mechanism for holography.

Government and Academic Guidance on Dual-Use Technologies

- National Science Advisory Board for Biosecurity (NSABB) (2007). *Proposed Framework for the Oversight of Dual Use Life Sciences Research*.
    - While focused on biological research, this framework offers useful structural analogs for assessing and managing dual-use risk in quantum physics.
- U.S. National Academies of Sciences, Engineering, and Medicine (2018). *Dual Use Research of Concern in the Life Sciences: Current Issues and Controversies*.
    - Highlights the tension between open research and national security, emphasizing the need for anticipatory governance.
- U.S. Department of Defense (2021). *Directive 3000.09: Autonomy in Weapon Systems*.
    - Though not specific to quantum systems, this directive reflects growing attention to emergent technologies and the need for ethical guardrails.
- OECD (2022). Recommendation on Responsible Innovation in Neurotechnology.
    - Offers a transferable policy structure for evaluating ethical and dual-use issues in high-impact emerging technologies.
- European Commission High-Level Expert Group on AI (2019). *Ethics Guidelines for Trustworthy Artificial Intelligence*.
    - While focused on AI, the general principles—transparency, accountability, and prevention of misuse—are highly applicable to quantum simulation and entanglement science.
- United Nations Office for Disarmament Affairs (UNODA):
    - *Science and Technology Developments Relevant to the Biological Weapons Convention*

- *Emerging Technology and Global Security* reports address the importance of foresight and responsible innovation in potentially transformative technologies.

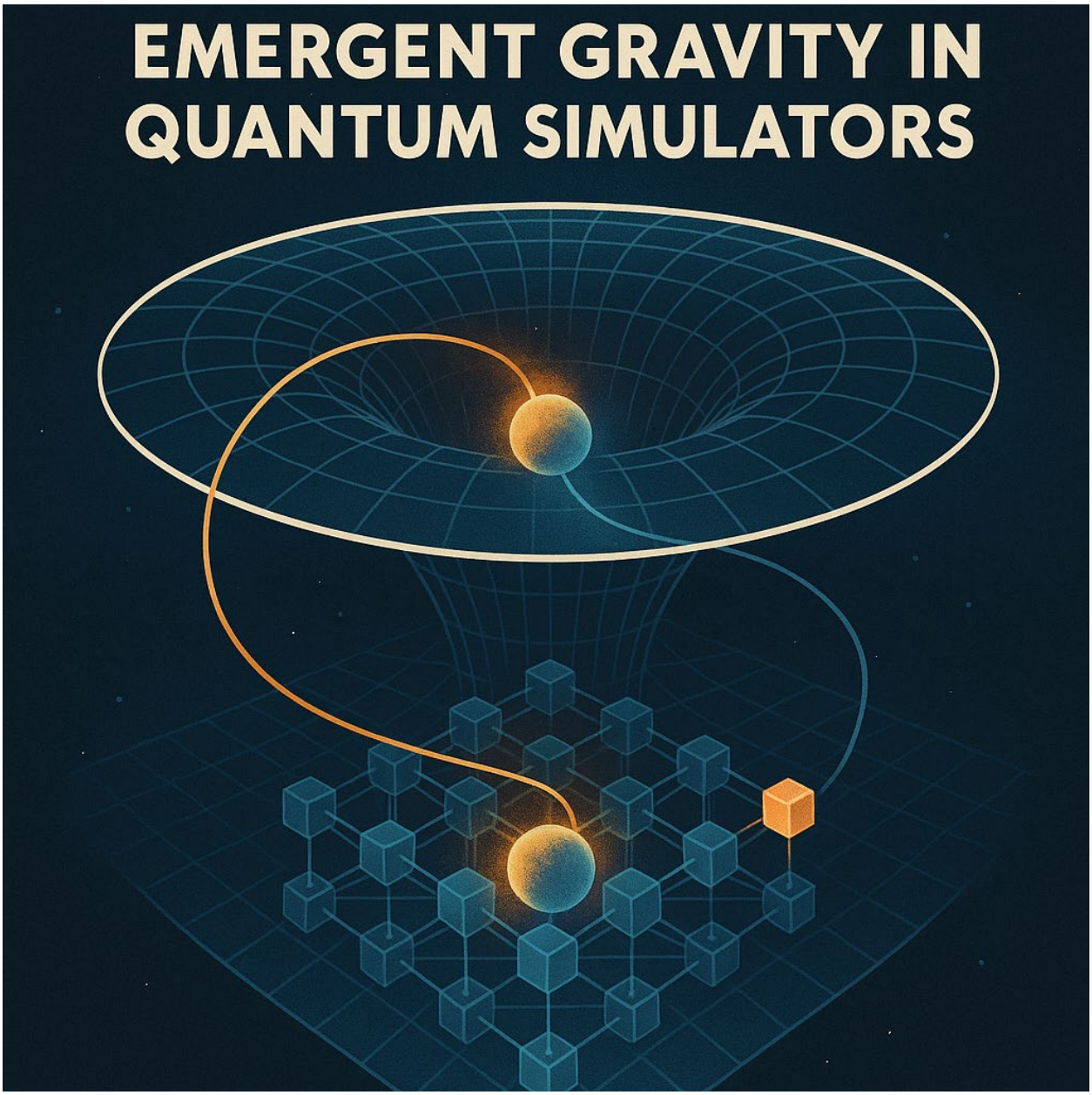
Additional Scientific Sources Referenced in the Analysis

- Qi, X. L. (2013). *Exact Holographic Mapping and Emergent Space-Time Geometry*. arXiv:1309.6282.
  - Provides a framework for understanding the emergence of bulk geometry from quantum entanglement structures.
- Chua, V., & Swingle, B. (2016). *Holographic Entanglement Renormalization of Topological Insulators*. Physical Review B, 93(3), 035115.
  - Discusses applications of MERA to systems with nontrivial topological properties.

Additional References from 2025 ResearchGate Preprints (Youvan, D.C.)

- Youvan, D.C. (2025). *From Quantum Computers to Natural Calculators: Understanding Atoms and Molecules as Quantum Calculators*. DOI: 10.13140/RG.2.2.34519.85925
  - Explores how fundamental particles may act as quantum calculators, contributing to the broader narrative that emergent computation from quantum substrates can lead to macroscopic effects resembling physical laws.
- Youvan, D.C. (2025). *Redefining Reality: Exploring the Physicality of Unreal Outcomes in Quantum Mechanics*. DOI: 10.13140/RG.2.2.19196.05769
  - Argues for reinterpreting counterintuitive quantum outcomes as physically real, aligning with themes of emergent spacetime from abstract entanglement structures.

- Youvan, D.C. (2025). *Synchronicity as a Feedback Mechanism: AI-Enhanced Cognition and the Unfolding Universal Order*. DOI: 10.13140/RG.2.2.30512.75521
    - Discusses cognitive models shaped by synchronistic quantum behaviors, further highlighting how perception and measurement in quantum systems can yield emergent patterns relevant to theoretical physics.
- Youvan, D.C. (2025). *Divine Inspiration and Intellectual Curiosity: A Unified Path Toward Peace*. DOI: 10.13140/RG.2.2.17746.12488
    - Reflects on the philosophical and ethical implications of emerging quantum technologies, resonating with the policy and ethical sections of this paper.
- Youvan, D.C. (2025). *AI and the Divine: Speculating on Technology as a Conduit for Spiritual Miracles*. DOI: 10.13140/RG.2.2.13491.36641
    - Suggests that entangled quantum systems may play a role in future spiritual or transcendent interpretations of physical law—relevant to potential dual-use paths for symbolic or informational power projection.


EMERGENT GRAVITY IN
QUANTUM SIMULATORS